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Enhancing Systems Engineering education through case study writing

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Abstract

Developing and refining methods for teaching systems engineering is part of Systems Engineering grand challenges and agenda for research in the SE research community. Retention of systems engineering knowledge is a growing concern in the United States as the baby boom generation continues to retire and the faster pace of technology development does not allow for younger generations to gain experiential knowledge through years of practice. Government agencies, including the National Aeronautics and Space Administration (NASA), develop their own curricula and SE leadership development programs to "grow their own" systems engineers. Marshall Space Flight Center (MSFC) conducts its own Center-focused Marshall Systems Engineering Leadership Development Program (MSELDP), a competitive program consisting of coursework, a guest lecture series, and a rotational assignment into an unfamiliar organization engaged in systems engineering. Independently, MSFC developed two courses to address knowledge retention and sharing concerns: Real World Marshall Mission Success course and its Case Study Writers Workshop and Writers Experience. Teaching case study writing and leading students through a hands-on experience at writing a case study on an SE topic can enhance SE training and has the potential to accelerate the transfer of experiential knowledge. This paper is an overview of the pilot experiences with teaching case study writing, its application in case study-based learning, and identifies potential areas of research and application for case study writing in systems engineering education.

Keywords: systems engineering; systems engineering pedagogy; case study; case study writing

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1. Introduction

Developing and refining methods for teaching systems engineering is part of Systems Engineering (SE) grand challenges and agenda for research in the SE research community[i]. Retention of systems engineering knowledge is a growing concern in the United States as the baby boom generation continues to retire and the faster pace of technology development does not allow for younger generations to gain experiential knowledge through years of practice.[ii] Systems Engineering programs across the United States struggle with identifying and developing appropriate curricula to prepare students for practicing systems engineering professionally. Departments of engineering at universities wrestle with the challenge of squeezing SE curricula into already overprescribed engineering undergraduate programs of study. Engineering students often do not see the relevance of SE to their future careers.[iii] SE research agendas suggest or illustrate approaches to SE pedagogy. The International Council on Systems Engineering (INCOSE) prescribes SE curriculum architecture for SE education.[iv,v] The use of case method (case study learning) in software engineering has been introduced as an alternative to theoretical emphasis typically encountered in engineering education.[vi] Research approaches marrying systems engineering and qualitative research including applying systems engineering to survey research[vii], but the field is still developing.

Government agencies, including the National Aeronautics and Space Administration (NASA), develop their own curricula and SE leadership development programs to "grow their own"[viii] systems engineers.[ix,x] NASA has developed policy, guidance, training, and competency profiles to guide the on-the-job or employer-provided SE education to meet the diverse agency systems engineering applications. Marshall Space Flight Center (MSFC) conducts its own Center-focused Marshall Systems Engineering Leadership Development Program (MSELDP)[xi], a program consisting of competitive selection, coursework, guest lectures, and rotational assignments into unfamiliar systems engineering organizations.

Independently, MSFC developed several open centre-wide courses to address knowledge retention and sharing concerns, namely its Real World Marshall Mission Success course and its Case Study Writers Workshop and Writers Experience. The Systems Engineering Management Office (SEMO) within the MSFC Chief Engineers Office identified the potential for the Case Study Writers Workshop and Writers Experience to benefit knowledge sharing in systems engineering to enrich training and build decision making skills. Teaching case study writing and leading students through a hands-on experience at writing their own case studies on an SE topic can enhance SE training and has the potential to accelerate the transfer of experiential knowledge.

This paper is an overview of the pilot experiences with teaching case study writing, its application in case study-based learning, and identifies potential areas of research and application for case study writing in systems engineering education.

1.1. Learning through case studies

Medicine and business schools heavily employ case study-based learning into graduate curricula. The benefits of case study-based learning include deeper situational awareness, group discussion of decision making issues rather than prescribed normative decision making practices, and broader insight of conflicting points of view. Case study-based learning can enhance the teaching of decision making thinking, and increase awareness of bias and assumptions.

Systems engineering graduate curricula may include a type of case study writing, but generally very little case study-based learning. More typically, case study writing in SE-related courses such as Engineering Management are more common than in SE-focused courses. While basic English courses (in the United States) and writing or research writing are required for undergraduate graduation, classes typically do not include instruction on how to write a case study. Qualitative research methods are not typically taught to engineering students; survey methods and grounded theory are more frequent in engineering management or program management research than in systems engineering.

1.2. Case Study Writing

Case studies can come in many different forms depending on the intended application envisioned by the case study author.[xii] Case studies can vary in length from one page to several hundred. Across the range of types of and applications for case studies, two general types have potential to accelerate the transfer for experiential knowledge and hone skills needed in the practice of systems engineering.

The two application areas are in 1) decisional case studies and 2) case study research. Students can hone systems engineering thinking and leadership skills through case study-based learning and case study writing geared to teaching through decisional or situational case studies.[xiii] Students can gain deeper understanding of both systems engineering practice itself and conduct systems engineering research through academically rigorous case study development. The two areas of case study development differ regarding the goal for using the end product (case study) and the rigor in which data need to be gathered, analyzed, and interpreted.

This paper will focus on case study writing for decisional situation illustration. Additional research is required to develop methodologies for incorporating academic case study-based research into systems engineering curricula. Follow on research opportunities are provided at the conclusion of the paper.

1.3 Case Study-based Research

System engineering struggles to define the scientific theory base for the discipline within engineering. Pennock and Wade[xiv] suggested that mechanistic, reductionist philosophy is a limiting foundation for justifying systems engineering practices. Qualitative research methods may be employed in systems engineering research to enhance understanding of the nature of complex systems and the complexities of engaging a variety of organizations in the creation of a system.[xv] Case study-based research is a qualitative research method used in "softer" sciences such as psychology, sociology, or human-centric disciplines such as education and medicine[xvi]. Case study-based research itself, as a scientific methodology, requires adherence to formal research and review structure to ensure validity of conclusions inferentially drawn from the research project. Case study research can be conducted as a standalone methodology or combined in mixed methods in the tradition of grounded research.[xvii] While not directly addressed in this paper, case study research could prove to be a viable approach to validating SE practices currently based predominantly on heuristics and as a method for grounding social science-based systems models.[xviii]

1.4 Case Study-based Learning – Decisional, situational case studies as a teaching tool

Yin states that rigorous case study research methods are not all necessary when using a case study as a teaching tool, such as in business, medicine, or law. He states, "For teaching purposes, a case study need not contain a complete or accurate rendition of actual events. Rather, the purpose of the teaching case is to establish a framework for student discussion and debate."[xix]

2.0 Case Study-based Learning at NASA

2.1 Learning Through Case Studies

NASA collects and makes available short and medium length case studies for teaching and discussion in a variety of topics. Most cases widely available focus on decision making, either by management, program management, systems engineering, or engineering leadership. Many reflect conundrums regarding risk or program administration. Cases are generally 1 to 12 pages long with illustrations, although some may be longer. On occasion, both a longer, more detailed case study will also have a companion summarized version so that the version can be selected based on the learning objectives of the class.

NASA uses case studies to illustrate program management and some limited engineering principles in training courses, including those provided through the Academy for Program/Project and Engineering Leadership (APPEL) training provider. Individual NASA Centers also create their own curriculum to develop engineering and program leaders. Goddard Space Flight Center (GSFC)'s Chief Knowledge Officer (CKO), Dr. Edward Rogers, created a more generalized course open to all Center civil servants which primarily uses case studies and discussions with Center leaders. The course, Road to Mission Success (RTMS), is limited to GSFC personnel to focus on GSFC-specific product base and Center culture and missions. In this way, Rogers can highlight typical work situations experienced by Goddard systems engineers, Center leaders, and program managers.

Roger's Road to Mission Success course has been unique across NASA in that it utilizes case studies in a planned and well-facilitated manner. Rogers wrote the GSFC-focused case studies used in the course over the past decade.

Such case study-based learning provides students with decisional scenarios in which the conclusion is not evident and alternative courses of action are counterpointed. Students discuss potential decisions in small groups and then talk through the case with the whole class. Rogers facilitates the discussion, often engaging a guest presenter who was involved in the scenario. The guest presenter provides background and details not captured in the case itself. The dialog between students and the guest increases the students understanding of the situation and the thought processes involved in making justified decisions.

There are several sources for case studies used in NASA courses. Dr. Rogers, authored several dozen case studies centred on experiences at GSFC. Some of these GSFC case studies focus on systems engineering decisions and conundrums. Internally to NASA, the NASA Safety Center (NSC)[xx] and the NASA Engineering Safety (NESC) have developed written case studies, some of which include companion videotaped interviews with primary participants featured in the corresponding case study. The former CKO of the Human Exploration and Operations Mission Directorate (HEOMD), Dr. David Lengyel, collected a variety of case studies from across NASA, primarily focused on risk management. Other engineering "cases" used in internal NASA courses are taken from independently authored books on design failures, such as Diane Vaughn's Challenger Launch Decision[xxi] and Petroski's Normal Accidents.[xxii] Often, collections of lessons learned accompany compilations of NASA case studies. University students or faculty occasionally write decisional case studies based on sources published externally to NASA, frequently focusing on organizational dynamics from a business school perspective, often for highly visible incidents such as the Challenger[xxiii, xxiv] and Columbia accidents[xxv], for which a body of public information exists.

2.2 Case study-based learning at Marshall Space Flight Center

In 2012, NASA recognized the need to expand knowledge capture and sharing from a focus on lessons learned to a broader vision knowledge services and complementary knowledge initiatives. Observing the benefits of developing a shared vision and institutional knowledge through the GSFC RTMS, Marshall Space Flight Center developed a similar course, Real World Marshall Mission Success (RWMMS) as part of their knowledge strategy for coping with the demographic problem. Other knowledge practices such as reflective learning through Pause and Learn practice, institutional collaboration in knowledge sharing, the distilling and infusion of lessons learned into policy, practices, and awareness, and involvement in Agency and Federal knowledge management communities complement the RWMMS course. Most notably, another MSFC initiative, case study writing, was developed as part of the MSFC knowledge strategy to leverage the power of case study-based learning. The emphasis for both RWMMS and case study writing has been on the "real world" of Marshall mission success.

Like Goddard's RTMS, Marshall's RWMSS course is evenly split between case study-based learning and discussions with Center leaders. Panels of experienced personnel discussing common experiences are also conducted. Sharing knowledge through case studies provides a context surrounding the experience and communicates the dynamic, human-centric, emotion filled situations encountered when schedule, budget and highly technical decisions are required under time constraints and with high consequences. Students are immersed in the context of a decisional situation and limited time to develop an appropriate solution. Case study learning also facilitates open communication and thoughtful conversation that promote mission success.[xxvi]

2.3 Case Study Writing at Marshall – A Genesis

A paucity of MSFC-focused case studies was encountered when developing the RWMMS learning plan. Similar to the dilemma of having a much shorter time in which to share knowledge, MSFC also has a much shorter time span to develop case studies to be used in RWMMS. To address the need for MSFC-focused case studies for RWMMS, a new course, the Case Study Writers Workshop and Writers Experience was developed in an effort to leverage the talents of interested Marshall employees in producing a body of knowledge contextually captured in well-written case studies. Teaching decisional case study writing had not been developed at NASA.

The new course leveraged a general case study writing process developed by Dr. Rogers as documented in the Selected NASA Case Studies. A 1½ day writers workshop was piloted in June 2014 conducted by the MSFC Chief Knowledge Integrator (CKI). Subsequently, a 10 week writers experience was conducted with teams of 2 writers from the workshop to generate unique case studies. Each team paired an experienced, senior Marshall member with

a more junior member. Students were from a variety of organizations across the Center, which is encouraged.

Two teams emerged from the pilot program, and two case studies were completed to a solid final draft stage by the end of the 16 weeks. In 2015, a slightly longer 2 day workshop was held in April 2015, with the writers experience extending for 18 weeks. Most teams focused on program management or Systems Engineering issues. One team addressed an engineering issue facing a launch decision, and one team highlighted an Center Operations decision. Table 1 illustrates the demographics of the teams involved in the Case Study Writers Experience to date.

Table 1. Case Study Writers Experience teams.

Team Subject Area	Senior Partner SE knowledge (range)	Junior Partner SE knowledge (range)
Government-contractor relationships (PM)	High	Medium
Launch decision – technical issue (SE)	(Mentor only; high)	None
SE implementation small project (SE) (Included highly experienced mentor)	Medium	Medium
Small Project PI-led SE implementation (SE)	Low	None
Launch Decision – technical issue	High	None
Launch Decision – technical issue (PM)	High	Medium
Center Operations large facility decision	Low	Low

A Pause and Learn activity was conducted at the end of each session, and lessons learned were incorporated or will be incorporated in the next offering of the course. A few observations were notable:

- Writers typically can produce a good final draft of a case, but usually not a highly polished case
- Teaming senior and junior writers is an extremely effective knowledge sharing strategy
- Working in teams provides accountability and perspective when working crafting the story
- A Writers Experience demands time spent in interviewing, condensing information, and finding the story. Writers have to know going in that it will take time, and commit to the process. Their management should be bought into the commitment also.
- The senior partner must be committed to being available and participative. The relationship between senior and junior partner must be supportive and open. Senior partners can learn as much as junior partners through this exercise.
- Regular tag up meetings are required to keep writers/writing teams on track and to help them through each step of the process. Writers also find that meeting regularly and sharing what they are working on is very beneficial and interesting.
- It is very helpful to have a list of pre-screened topics with an agreeable point of contact to help students find a case study topic if they don't already have one, and to get them pointed in the right direction or to the key people to interview.

After the final session of the Writers Experience, only a few teams felt "done". Some writers encountered unforeseen impediments; the most significant was when one or both of the team members were withdrawn due to detail assignment, a family medical issue, or the demands of work responsibilities. Writers generally were intellectually engaged early on and developed a desire to keep going despite time challenges. Most writers were committed to sharing their case studies in the inaugural offering of RWMMS in August, so some polishing was required between the final WE session in late July and the RWMMS sessions in August and September 2015. The two case studies from the 2014 pilot CSWE, and three case studies from the 2015 CSWE were presented by their authors in RWMMS. A fourth case study from the 2015 CSWE was presented by a centre leader at his request. A fifth case study from the 2015 CSWE was presented as a panel discussion on Principle Investigator versus Program Manager-led small projects.

2.4 Key Elements of Case Study Writing for Decisional Cases

The outline provided by Dr. Ed Rogers in writing case studies proved to be a good framework for teaching case study writing. As writers progressed through the steps, it was evident that certain skills were not natural or trained in students of the course. These skills include:

2.4.1 Getting comfortable with non-closure of the story

Most writers are engineers or professionals who are accustomed to writing conclusive reports, with summaries at the beginning and a distinct bottom line. Decisional case studies demand that the writer develop a story line and conclude with the decisional conundrum, leaving the "answer" open and subject for discussion. In contrast, EVERY team wants to tell "the rest of the story". As a compromise, writers are allowed to write appendices that tell what happened in the end.

While presenting the case in RWMMS, writers begin to see the utility in leaving the question open. The openness of the case also allows an invited guest, often one of the key participants of the actual event, to discuss the situation without giving the answer, and then concluding with the rest of the story. Writers also often employ a "Stop and Think" mechanism where there are several parts of the case, with stopping points to debate specific principles and highlight the thought processes used in decision making.

2.4.2 Interviewing skills

Most of us don't have interviewing skills. Methods of face-to-face inquiry aren't taught. Following a line of inquiry when you don't know the point of the story can be challenging. Even after identifying a story focus, keeping an interview on topic can be difficult – getting off topic can prove to be interesting but not productive, or getting off topic can prove to be beneficial, insightful, and provide a better focus for the story.

Interviewing also requires preparation to formulate a line of inquiry. Likewise, a systems engineers should know what they need to know before engaging in an inquiry. Preparing for interviews develops contemplative problem structuring.

2.4.3 Learning about something you don't quite know enough about

Teams start with an understanding of the project or situation they are writing on, such as the implementation of SE policy on a specific project. They may not understand what that entails. Especially, for the two teams that were specifically writing on systems engineering, while they had advanced concepts or academic knowledge of SE, they didn't have project application through a life cycle knowledge of SE. One team was fortunate to have two junior partners and sage tutelage from the senior who acted as a mentor as much as a partner. The other team had to do a lot of homework. In general, the amount of homework teams had to do was more than they expected, but provided information in context that they would not have learned otherwise. Teams also had to take the initiative to find and absorb the contextual knowledge surrounding the project or SE application, building their internal construct of the story. Teams had to seek knowledge instead of it being presented easily.

2.4.4 Finding the story in all the information

Team accumulated a wealth of information about the subject from a variety of sources. Students were taught that they needed complementary viewpoints to get a balanced perspective. Teams interviewed between 4-7 principle actors. From the wealth of knowledge gained in interviews, the partners had to identify the "story", winnow down to identify the most applicable information, and then craft the arc of the story. Teams were given a general format for establishing the context, establishing the conflict, telling the pertinent information, and ending in the decisional questions. Finding the story is analogous to having a SE or other decision maker find the story in the wealth of information provided during technical reviews or design decisions. Identifying the significant from the trivial or the need to know from the anchoring information emerges as teams discuss how to craft the story.

2.4.5 Concept Mapping as a tool for note taking

Introduced as an alternative form for note taking during interviewing, concept mapping aided some teams in recalling and discussing pertinent information gained from interviews. Concept mapping. It is not common to find MSFC employees adept at and frequently employing concept mapping as a note taking strategy, although it can be used to represent systems and is applied in systems development and business modelling in industry.[xxvii] Trochim provides some background to concept mapping.[xxviii] A resource guide is available on the web.[xxix] Concept mapping is a form of information representation that underlies the idea of modelling in soft systems methodology[xxx], systemigrams[xxxi], and mind mapping[xxxii]. Using concept mapping to map conversations to recall and process oral information has potential to support the analysis of the cognitive roots and tool development in systems engineering.

2.4.6 Deep learning of the content

All case study writing involves deep learning of the subject. Some of the writers had trepidations about presenting their cases, especially the junior writers. One junior writer, whose partner was pulled off on a detail assignment presented his case study in a staff meeting a few weeks before presenting at RWMMS. Not only did this give him confidence in being able to discuss the issue, he found parts of the story needing more clarity, and that different issues were highlighted depending on the audience viewpoint. Another writer discovered how much he had learned about the subject, finding it easy to talk about the issues and communicate relevant facts. All writers developed confidence in the knowledge of their cases. Presenting at RWMMS reinforced their confidence and amplified their understanding of differing viewpoints and interpretations.

2.4.7 Emotion is always present

Decision making in high consequence and time and resource constrained environments always involves some level of emotion. Interviewees sometimes communicate what they felt, but frequently, if the situation were particularly trying, they may have forgotten or buried the emotions, or were hesitant to revisit those memories. Sometimes they don't realize the emotions were as profound as they contemplate them retrospectively. Dr. Rogers warned that sometimes talking through the case studies can be cathartic or therapeutic for students and key players. Case study writers observe the dynamics of emotion in a way not typically experience din other knowledge sharing methods.

One team wrote about a small, hands on project that was selected to also be a hands-on learning experience for a new PM and a new Chief Engineer. They had to apply MSFC policy regarding systems engineering products and reviews. The project had been led by a PI. The case study was being written very shortly after the strife of the PI versus PM issues were experienced. Emotion was still present. Interestingly, when the case study writers sent their final draft to the stakeholders, the stakeholders commented that seeing the other side's viewpoint represented in that format helped them to clarify the experience and understand the dynamics of very recent events. The unintended consequence was greater understanding on many sides regarding why the struggles manifested.

It is not recommended that case studies be used that soon after a conflict, although if done a long time after an experience, key players may have forgotten details. Timing might make a difference in the results from the case study writing. Management may learn more about their organizations in a reflective learning way through case study development and writing at their institution.

3. Conclusions

Learning from case studies about systems engineering issues, conundrums, and decisions encountered in practice can be a rich source of pseudo-experiential learning. Similar to conducting simulations of system operation or simulating experiment procedures for International Space Station operations, case studies enable students to mentally simulate the environment, dynamics, and conundrums faced by real systems engineers in the real world. Case study-based learning provides contextual knowledge that can be entrained more richly. Case studies also illustrate differing

points of view without necessarily taking sides on which is right or which is wrong. Balancing equally valid but not necessarily equally weighted priorities is an important skill for systems engineers to develop.

Case study writing may prove to be a beneficial tool for organizations to teach skills important in executing good systems engineering, such as being comfortable with non-closure, identifying the important information during discussions, inquiry skills, and deep contextual knowledge about decision making. Case study-based learning provides a conceptual simulation of actual systems engineering practice that can enrich SE skill development. In the INCOSE Graduate Reference Curriculum for Systems Engineering (GRCSE®),[xxxiii] case study research could be introduced to support systems thinking whereas case study writing could be introduced to support the area of systems approach to applied engineering.

More research is warranted in discovering if case study writing can be utilized more effectively in SE curriculum to enhance the learning process. A key element would be to have a cooperating organization where students could have access to the relevant people and background information of a case study, and have a case study writing curriculum that nurtures writers through the process.

One outgrowth of the Marshall experience with case study writing is the potential for employing case study research or a more rigorous kind for graduate students. Systems engineering research may be enhanced through the addition of the benefits of qualitative research applied to systems engineering practice.

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